1) **Principal Investigator**: R. L. Coulter, Argonne National Laboratory
Co Investigator: B. M. Lesht, Argonne National Laboratory

2) **Grant Title**: Scales and Heterogeneities of Surface Albedo and Fluxes

3) **Scientific Goals**:

The ultimate goal of the proposed research is to develop and test parameterization schemes for inferring spatial and temporal variabilities in surface albedo, heat fluxes, temperature, and humidity by using satellite-based remote sensing data and limited ground-based measurements. Within this context, the objectives are:

a. Study the relationships between variability in surface vegetation and soil type and moisture and the systematic errors in modeled surface albedo, latent and sensible heat flux, and surface temperature and humidity.

b. Develop methods to estimate regional surface heat fluxes and related surface thermal and moisture properties across the CART site by using limited ground measurements, satellite remote sensing data, and associated inversion techniques.

c. Improve an existing land surface model driven by satellite data and apply it to characterize variabilities in surface thermal and moisture properties and fluxes and to estimate their regional representative values and variability ranges across the SGP CART site.

d. Investigate the effects of regional surface fluxes on the planetary boundary layer structure by using available remote sensing and balloon profiles of meteorological parameters.

4) **Accomplishments** (bullets):

- A method for estimating local sensible heat fluxes using Oklahoma Mesonet data has been developed using a bulk aerodynamic technique. These data are being integrated with ARM EBBR and ECOR surface fluxes to provide enhanced coverage across the SGP CART site.

- The response of the atmosphere's mixed layer to gradual changes in topography was investigated using data from a cooperative IOP with the CASES99 field study. This provides an indication of the rate at which surface spatial scales are integrated by the lowest 1-2 km of the atmosphere.

- High resolution (200 m) estimates of soil root-zone moisture within the SGP CART have been made using satellite radiance and limited surface meteorology and land-use data.

5) **Accomplishments**

a) Estimates of Planetary Boundary Layer (PBL) mixed layer depth (Zi) have been made at the ARM SGP CART site by objective and subjective examination of radar wind profiler vertical time sections of signal strength since 1997, when the three intermediate facilities at Beaumont (be), KS, Medicine Lodge (ml), KS, and Meeker (mk), OK were installed and were augmented by two additional profilers at Whitewater (wh), KS and Oxford (ox), KS. The subjective evaluations have been used to estimate the "final" height of the mixed layer, defined as the height at 1500 LST at each of the 5 sites. Because Zi is driven primarily by the surface heat flux, H, and the atmospheric stability and normally reaches 1-2 km in height, it should respond to H over a larger surface area than is normally sampled by available direct measurements. To test this hypothesis, the surface heat flux, averaged over varying numbers of ARM extended facilities, integrated between 0800 and 1600 LST along with an estimate of atmospheric stability derived from daily balloon sonde releases at 0530 LST from the central facility were correlated with Zi. Correlations between Zi measured at the CF and the ratio of H/S where S is the potential temperature gradient between the surface and the maximum potential temperature within the lowest 2 km for different regions over which H is averaged (Table 1) vary between 0.36 and 0.71. The lowest correlation is always that with only a single site (central facility) and the highest is using the maximum number of stations and a mean of Zi from all the profilers.

Time	Location of ZI measure	Surface Flux average area	Correlation Zi:H/(dq/dz)
1998	cf	cf+ashton	0.55
1998	cf	cf+ashton+ringwood	0.57
1998	cf	cf+ashton+ringwood+TGP	0.54
1998	cf	all	0.55
1998	cf+ml+mk+be+wh	all	0.71
1999	cf	cf	0.36
1999	cf	all	0.55
1999	cf+ml+mk+be+wh+ox	all	0.58
1998 - 99	cf+ml+mk+be+wh+ox	all	0.63

It is unreasonable to expect that the local values of Zi should consistently correlate best with scales on the order of the whole CART site, since Zi is always less than 3 km. The best correlation is most likely with surface elements on the order of 30 km. In order to further test this relationship, we have devised a method to use the data from the OK mesonet to estimate local sensible heat flux at each of the mesonet sites. Using a bulk aerodynamic calculation and parameterizations of net radiation based on measured solar radiation and surface type, estimates of H are obtained that compare favorably with sitewide estimates of H using the EBBR data (Figure 1). The combined data from the ARM and OK networks can now be used to refine the results of Table 1.

b) The triangle of profilers within the ABLE region (60 km separation) was studied in some detail as part of an Intensive Operating Period (IOP) in cooperation with the CASES99 field study during October 1999, during which the profiler network (wh, be, ox) was augmented by two sodars at leon (le), located roughly one third of the distance between be and wh, that had range resolutions of 15 m. Due to a lack of precipitation and senescent vegetation, surface differences were minimized except for topography. Considerable variation in Zi even across small regions occurs even during meteorologically homogeneous conditions. In these conditions the differences should be related primarily to differences in surface topography.

   Over the 26 day period a consistent afternoon difference among the sites is evident. Differences during morning hours are almost impossible to generalize even over a 26 day period because of rapid growth in Zi during this time period. When the different surface altitudes of (ox, wh, le, be) are accounted for, the mixing process over the ABLE region appears to tend toward a geopotentially constant mixed layer. Figure 2 illustrates that, in the mean, over 60 km scales the atmosphere is somewhere between geopotential adjustment (surface differences are "absorbed" to some mean value by the atmosphere; likely at small scales with relatively small differences in elevation) and constant surface adjustment (likely at large separations and large elevation differences). Indeed, the average difference between Zi values during afternoon at le and be is almost the same (but opposite sense) as the surface height difference, indicating little or no adjustment away from geopotential has occurred within 17 km horizontal distance.

c) A model framework for parameterized subgrid-scale surface fluxes (PASS) has been modified and applied to infer root-zone available moisture (RAM) content over a 60 km X 60 km region of the SGP CART site using satellite data and limited surface observations. Data collected during the 1997 CASES field campaign at the ABLE site in the Walnut River Watershed in Kansas (northeastern portion of the SGP CART site) were used to evaluate the approach, which inferred RAM at times of satellite overpasses during cloudless conditions. Data from the NOAA-14 AVHRRs were collected and adjusted for atmospheric effects by using LOWTRAN7 and local radiosonde profiles. Input variables for PASS consisted of NDVI and surface radiant temperature, together with observations of down welling solar irradiance, air temperature, relative humidity, and wind speed. Surface variables were parameterized using satellite data and land use information; pixel-specific near-surface meteorological conditions were adjusted by local surface forcing.

   Finally, RAM content was estimated using surface energy balance and aerodynamic methods. Comparisons with radar cumulative precipitation and soil moisture estimates (Figure 3) indicated that the spatial and temporal variations of RAM were simulated reasonably well. Modeled values of RAM content plus a representative value of wilting point moisture content agreed on average with observed soil moisture content to within 6% for the mean, with a standard deviation of 15%. This version of PASS is intended to provide initial data (during clear conditions) for using a second version between clear-conditions satellite overpasses. This version also has the potential to provide

initialization and assimilation data for forecast and climate models, useful in the absence of dense networks of soil moisture measurements.

6. **Figure Captions**

Figure 1. Comparison between sitewide daily-averaged sensible heat flux (during daytime, 0800 - 1600 LST) measured with 10 ARM EBBR systems and at 50 Oklahoma Mesonet sites during 1998-1999. Oklahoma mesonet values are calculated with a bulk aerodynamic method that uses measured solar radiation, wind and temperatures.

Figure 2. Difference between afternoon mixed layer depth and the mean over the ABLE site during October, 1999. Differences decrease when they are calculated above a geopotential surface, indicating that the mixed layer is still sensitive to surface topography on scales of 50 km or more. If the mixed layer height was a constant height above the earth's surface the differences would be parallel to the dotted line; if it was at a constant geopotential height, they (the red line and dots) would be horizontal.

Figure 3. Patterns of root area moisture content calculated with the PASS (bottom 3 panels) and the cumulative 24-hour period rainfall immediately preceding the period of model calculation. Study area is the Walnut River, KS Watershed in the northeastern portion of the SGP CART site. Model resolution is 200 m.

7. **Publications**

Referred and Published:

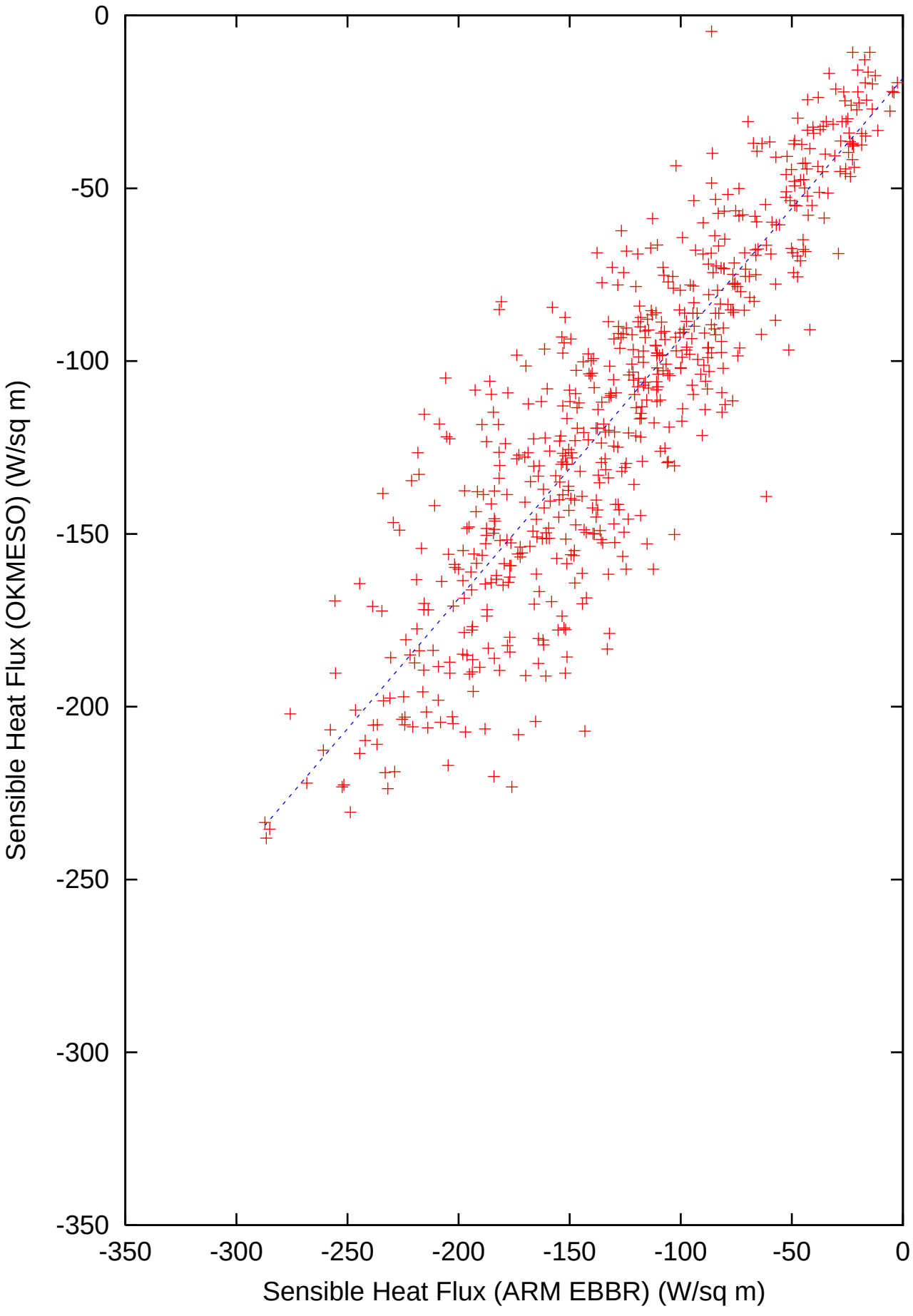
Jacobs, J. M., R. L. Coulter, and W. Brutsaert, 2000: Surface heat flux estimation with wind-profiler/RASS and radiosonde observations. *Advances in Water Resources*, **23**, 339-348.

Refereed and accepted for publication:

Song, J., M. L. Wesely, R. L. Coulter, and E. A. Brandes, Estimating Watershed Evapotranspiration with PASS. Part I: Inferring root-zone moisture conditions using satellite data. Accepted by *Journal of Hydrometeorology*.

8. **Extended Abstracts**:

Coulter, R. L. and J. C. Doran, Intermittent turbulence events observed with a sonic anemometer and minisodar during cases99. Preprints, 14th International Conference on Turbulence and Diffusion. Aspen, CO, American Meteorological Society, August 7-11, 2000.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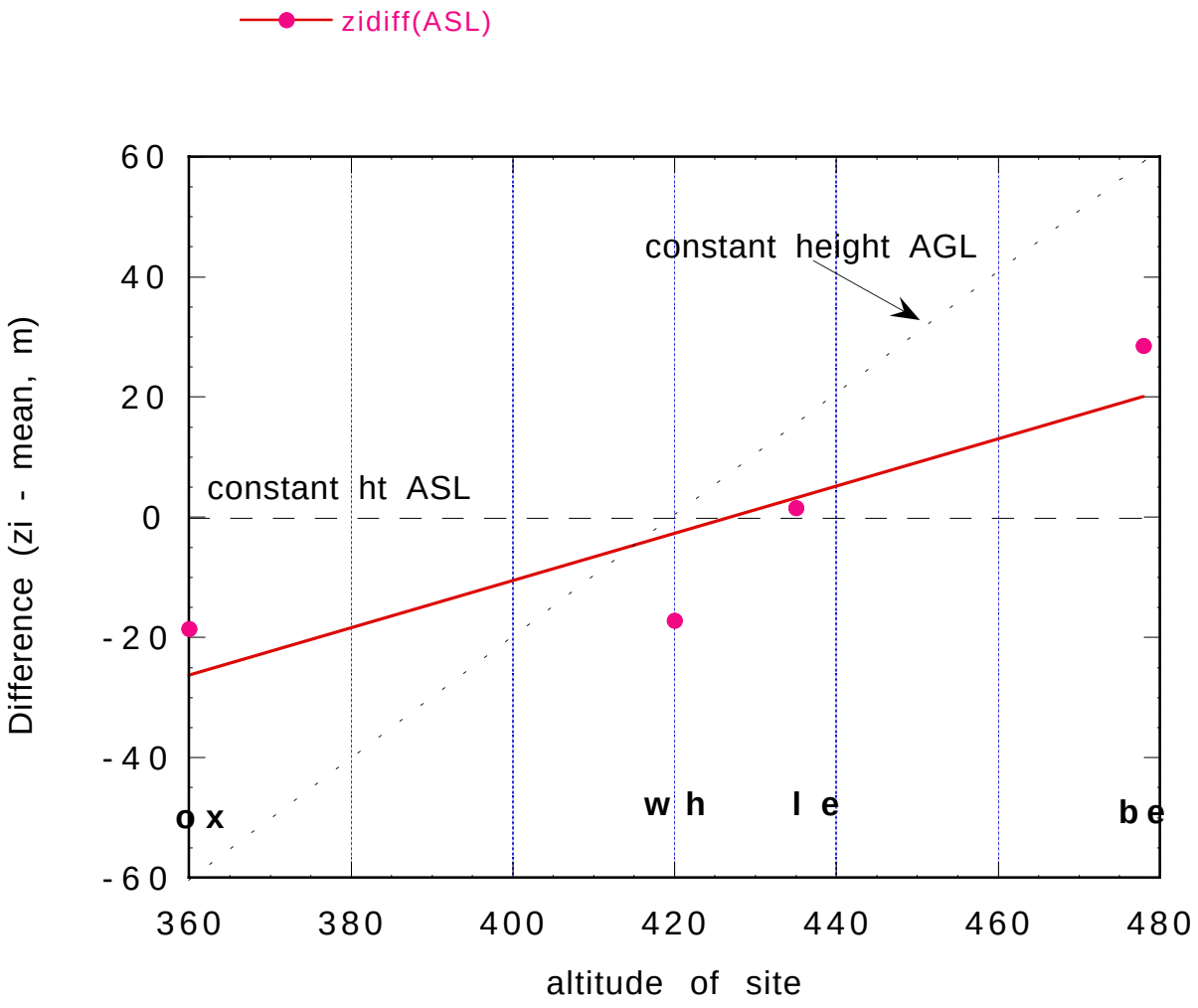
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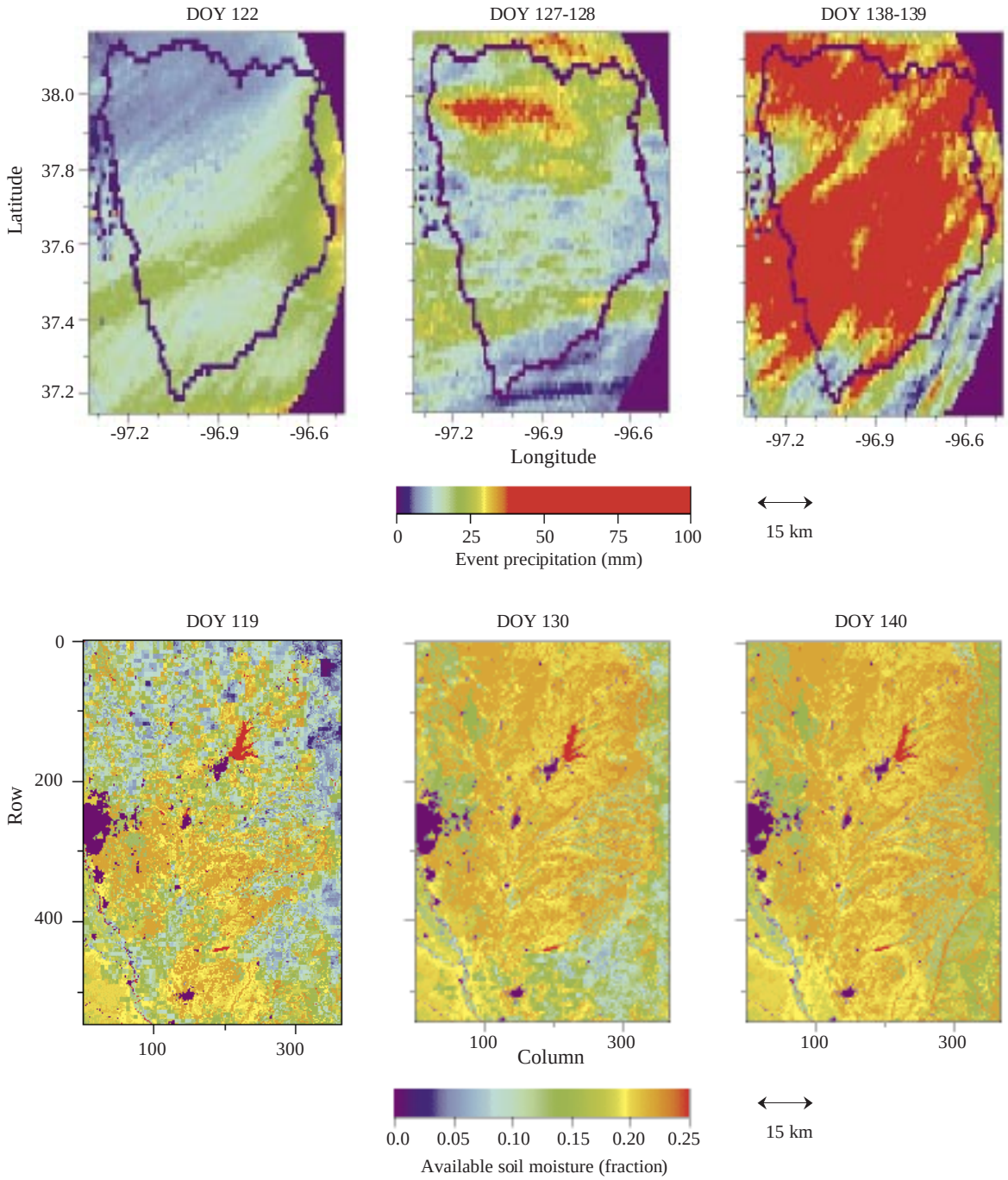
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300
Column
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0.10
0.15
0.20
0.25
Available soil moisture (fraction)
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